3.4A ACCURACY OF VELOCITY AND POWER DETERMINATION BY THE DOPPLER METHOD

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THE REQUIRED SUPPRESSION OF ANTENNA SIDELOBES NEAR THE MAIN LOBE

When designing an MST radar antenna one has to trade between the choices to optimize the effective aperture or to optimize the sidelobe suppression. An optimization of the aperture increases the sensitivity. Suppression of sidelobes by tapering attenuates undesirable signals which spoil the estimates of reflectivity and velocity. Generally, any sidelobe effects are equivalent to a broadening of the antenna beam. The return signal is due to a product of the antenna pattern with the varying atmospheric reflectivity structures. Thus, knowing the antenna pattern, it is in principle possible to find the signal spectra, which, however, may be a tedious computational and ambiguous procedure.

For vertically pointing main beams the sidelobe effects are efficiently suppressed because of the aspect sensitivity. It follows that sidelobes are a minor problem for spaced antenna methods. However, they can be crucial for Doppler methods, which need off-vertical beams. If a sidelobe is pointing towards the zenith a larger power may be received from the vertical than off-vertical directions, but quantitative estimates of this effect are not yet known.

To get an error estimate of sidelobe effects with an off-vertical main beam we discuss the following 1-dimensional example. This yields a reasonable estimate since the sidelobe closest to zenith, in the plane in which the main beam is steered, mostly dominate the errors.

Assume that the antenna pattern $P(\delta)$ in the plane in which the main beam is tilted is given by Figure 1. Let P_1 be the power gain of the main lobe at the zenith angle δ_1, and P_2 the power of the sidelobe at δ_2. The aspect sensitivity, given by $\alpha(\delta)$, changes the actual antenna pattern to an apparent antenna pattern, sketched by the dashed lines. It alters the direction and the power of the antenna lobes. For the following estimates we do not consider the apparent beam direction and we confine to the power in the main lobe at δ_1 and the first sidelobe at δ_2. The other sidelobes (at δ_2', δ_3' and δ_3) are reasonably suppressed by the aspect sensitivity and are not considered here. To get a worst estimate we also do not consider the doubling of sidelobe suppression for reflection and assume a one-way beam only (scattering).

From the Doppler spectrum $P(\omega)$ of the radar returns we get the average power

$$\overline{P} = \int P(\omega)\, d\omega,$$

and the average Doppler frequency

$$\overline{\omega} = \frac{\int \omega\, P(\omega)\, d\omega}{\overline{P}}$$

Assuming that the radar detected structures move with a velocity U in the plane of Figure 1, we would measure Doppler frequencies $\omega_1 = (-4\pi\, U \sin \delta_1)/\lambda_0$ and $\omega_2 = (-4\pi\, U \sin \delta_2)/\lambda_0$, and average (normalized) powers P_1 and P_2 through the main beam at δ_1 and the sidelobe at δ_2. Since the contribution from the main- and the sidelobe cannot be separated, we obtain the incorrect

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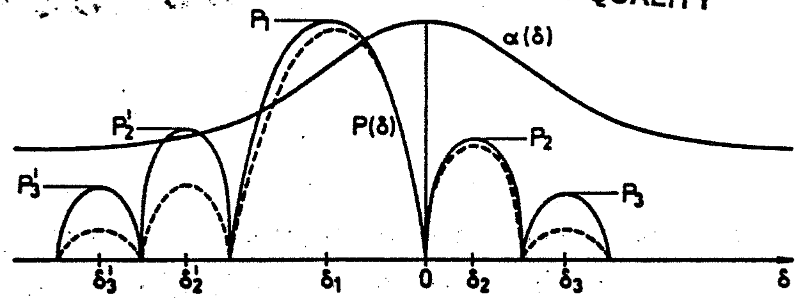

Figure 1. Schematic antenna pattern $P(\delta)$ in the vertical plane as function of zenith angle δ. The main lobe with power gain P_1 is tilted off the vertical at an angle δ_1. Sidelobes are shown at angles δ_2, δ_2', δ_3, δ_3'. The antenna pattern is weighted (dashed lines) by the aspect sensitivity $\alpha(\delta)$.

estimates

$$\overline{P} = a_1 P_1 + a_2 P_2,$$

$$\overline{\omega} = \frac{\overline{\omega}_1 a_1 P_1 + \overline{\omega}_2 a_2 P_2}{a_1 P_1 + a_2 P_2}$$

where $a_1 = \alpha(\delta_1)$ and $a_2 = \alpha(\delta_2)$.

If one would neglect the sidelobe effects, one measures the signal power ($\hat{=}$ radar reflectivity) and velocity with fractional errors

$$\Delta\overline{P} = \frac{\overline{P} - a_1 P_1}{a_1 P_1} = \frac{a_2 P_2}{a_1 P_1},$$

$$\Delta U = \frac{\overline{\omega} - \overline{\omega}_1}{\overline{\omega}_1} = \frac{a_1 P_1 + a_2 P_2 \cdot \sin\delta_2 / \sin\delta_1}{a_1 P_1 + a_2 P_2} - 1.$$

Using for example $\delta_1 = 9°$, $\delta_2 = -4.5°$ (without considering the apparent beam direction), $P_1 = 1.0$, $P_2 = 10^{-2}$ (for a worst estimate of -20 dB two-way-beam sidelobe suppression), and $a(\delta) = 1$ dB/degree corresponding to $a_1 = 1.3 \cdot 10^{-1}$ and $a_2 = 3.6 \cdot 10^{-1}$, yields $\Delta\overline{P} = 2.8 \cdot 10^{-2}$ and $\Delta U = -4.3 \cdot 10^{-2}$. This means that the power would be overestimated by 2.8%, and the horizontal velocity would be underestimated by 4.3%. A similar computation will yield the error estimates for the spectral width. Since δ and $P_{1,2}$ are known, instrumental parameters and $a(\delta)$ is fairly well known from observations, ΔP and ΔU can be used for correction, which will yield a very reasonable estimate of $\overline{P}$ and U. It, thus, may appear to be more feasible to apply corrections which have to take into account the two-dimensional pattern than use tapering. However, situations may occur (e.g., strongly tilted, reflecting layers) which would lead to substantial contributions through antenna sidelobes. These situations need special attention during the data analysis. To minimize the problems with tilted layers, it is recommended to swap the main beam direction, viz. measure at zenith directions δ_1 and $-\delta_1$, when applying the Doppler beam swinging method. A more reliable estimate of the tilt, however, can be deduced with the interferometer technique.